

Juvenile Chinook Salmon Diet in Comparison to Invertebrate Drift in the Merced River, California

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Diets and habitat types of salmonids have been widely studied in disturbed streams and rivers. The Merced River in California has a long history of flooding, damming, levee failures, and channel reconstruction events that has disrupted the aquatic ecosystem. This 30 day study was conducted in the Robinson Reach of the Merced River using juvenile Chinook salmon (*Oncorhynchus tshawtscha*). The objectives were to try and understand if juvenile Chinook salmon were selecting certain invertebrate species, determine if there were any differences in diets between habitat types, and determine whether diets and drift samples were different. Diets consisted of three major invertebrate families: Hydropsychidae, Baetidae, and Culicidae. Family Hydropsychidae was the most common composing of 35.9% of all salmonid diets at the time of the study. When comparing diets between habitat types, there was not enough evidence to suggest a significant difference between reference and artificial structure types ($p = 0.77$). Previous studies suggest that Chinook salmon diets closely resemble drift samples. However, our data provides evidence to suggest that diets and drift samples are different with family Hydropsychidae occurring mainly in diets. One hypothesis for this occurrence could be linked to the drift tolerance of certain invertebrate families like Hydropsychidae.

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Introduction

Juvenile Chinook salmon (*Oncorhynchus tshawtscha*) are considered to be primarily diurnal feeders that consume prey located in and around substrate (Syrjanen et al. 2011). One reason why juvenile salmonids feed during the day is that prey, such as freshwater invertebrates, can be easily located within a water column at that time. Past studies have illustrated that Chinook salmon are opportunistic foragers, with diets closely reflecting the composition of benthic and/or drift samples (Elliott 1973; Fraser and Metcalfe 1997). Typically, salmonids select foraging sites to minimize energy costs and maximize the availability of drifting prey per unit time characterized by the term sit-and-wait predation (Nakano and Kaeriyama 1995; Young et al. 1997). In general, salmonids that exhibit sit-and-wait characteristics feed on drift species like *Baetis spp.* from the Ephemeroptera order. When sit-and-wait habitats are sparse, salmonids tend to select benthic invertebrates such as species from the Trichoptera and Diptera orders (Nislow et al. 1998).

Course woody debris (CWD) and large boulders are vital for salmonid early life stages. This habitat is valuable for spawning, feeding, and cover from

predators (Yoshiyama et al. 1998; Zeug et al. 2011; Utz et al. 2012). Previous research has demonstrated that there has been a widespread reduction of Chinook salmon abundance in California which has prompted multiple stream habitat manipulation projects to restore populations (Williams 2006; Kondolf et al. 2008). Research has shown that spawning habitat degradation in natal rivers occurred as a result of hydraulic mining, damming, and water diversion projects (Utz et al. 2012). Habitat restoration projects were needed to try and improve valuable habitat. A recent study conducted on the Merced River, California, provided evidence to suggest that adding the right amount of course woody debris into a system could create desirable habitat to promote increased growth rates among Chinook salmon (Hafs et al. 2014).

This study was conducted on the Merced River, California, which is a 233-km-long tributary of the San Joaquin River flowing from the Sierra Nevada into the Central Valley. The Merced River had experienced multiple flooding events that created a sinuous river channel with developing point-bar geomorphology, and levee failures that created

braided and frequently ponded sections of the river (Utz et al. 2012). In 2001, following a levee failure, channel reconstruction of a 2.7-km-long reach began to restore the Merced River (CDWR 2001). Because ecosystem restoration was an up-and-coming area of management at the time, little was known about the amount of gravel augmentation or CWD that should be used to positively impact the life stages of all fauna in the Merced River.

Here, the diets of juvenile Chinook salmon were compared to invertebrate drift samples to 1) determine how much of an impact habitat complexities had on the diets of this salmonid. Based on previous literature, we would expect juvenile Chinook salmon located near a known structure (H) to have a more diverse and different diet than reference salmonids (R). We also wanted to 2) determine if caloric intake varied significantly between habitat types. Lastly, we wanted to 3) determine if diet and drift samples varied.

Methods

Study Site

The Merced River is a tributary of the San Joaquin River that drains 33,000 km² in the Central Valley and Sierra Nevada region of central California which represents the southern-most extent of the current Chinook salmon range. Salmonids are confined to a 39-km reach (known as the Robinson Reach) below the Crocker-Hoffman Dam that blocks upstream fish passage. This stretch of the Merced River was where this study occurred.

Study Design

The study lasted a total of 30 days beginning 15 March and continuing until 15 April 2012. A total of sixty 1 x 0.5 x 0.5 m enclosures were built from polyvinyl chloride plumbing pipes and 6.35 mm fine mesh, each of which held a juvenile Chinook salmon. The enclosures were set in a paired design in varying velocities throughout the Robinson Reach of the Merced River. Thirty enclosures were situated downstream of an artificial structure (H) to simulate a large boulder or down log. The remaining thirty enclosures were situated in areas of open water (R) in relatively equal velocities to the paired H enclosures. Each enclosure was cleared of floating debris every third day, with water velocities measured every sixth day upstream of each enclosure. Discharge was measured several times spanning the range of varying stage heights during the study to determine the volume of water each juvenile Chinook salmon had access to. Juvenile Chinook salmon remained in the enclosures for four weeks; all fish were pulled on 12 April from 0800 to 1415. The juvenile Chinook salmon were stored frozen at the end of the study to allow for dietary and percent dry weight analysis.

A total of 150 drift sampling events from 17 March to 15 April 2012 were conducted to determine invertebrate communities within the study reach. Sampling events lasted either 3600 or 7200 seconds that encompassed morning (M), noon (N), and evening (E) times of each day. A variation in the time of day sampled was necessary due to different feeding or drifting characteristics between invertebrate species.

Laboratory procedures

All invertebrates in the drift samples were identified down to family and had head widths measures at the University of California Riverside. Stomach contents from each Chinook salmon were extracted and placed into small vials filled with 90 percent ethanol. All distinguishable invertebrates in the stomach samples were identified to genus or the lowest taxonomic level possible. Head widths and counts of invertebrates were recorded to determine the total consumed mass per stomach. Equations provided in Benke et al. (1999) were used to convert all invertebrate head widths to total predicted mass. Predicted mass was calculated using equation 1:

$$\text{(Eq. 1) } M = aL^b$$

Where M is dry mass (mg), *a* and *b* are constants related to a particular family, and L is head width (mm). Following methods by Cummins et al. (1971), we were able to calculate a theoretical caloric value per invertebrate family based on dry mass. Caloric values were calculated using equation 2:

$$\text{(Eq. 2) } \text{Cal} = (\text{cal/gm}) \times \text{gm invertebrate}^{-1}$$

Where Cal is calories, cal/gm is calories per gram of dry weight, and gm is predicted weight from equation 1 of each invertebrate consumed. Calories per individual invertebrate were converted into kilojoules of energy to estimate the amount of energy consumed by our test salmonid.

Data Analysis

Program R was used to run statistical analysis to determine if there were differences in diets between varying habitats. A nonparametric multidimensional statistic (NMDS), within the vegan package of Program R, was run to provide evidence of any differences in invertebrate diversity among habitat types (Oksanen et al. 2015). In order to assess differences in invertebrate diversity among habitat types, the ellipse package was used to correlate the NMDS matrices with a 95% confidence region (Murdoch and Chow 2013). Matrices that plot close together in the ordination space are considered similar (Merovich and Petty 2007).

Using NMDS in Program R, comparisons were made between juvenile salmonids' diet and drift samples. In order to analyze differences between diets and drift samples, the ellipse package was used with a 95% confidence region (Merovich and Petty 2007).

A Shapiro–Wilk test was run to test for normality of the data for the two habitats' energy levels. Because the data was non-normal a Wilcoxon paired test was used to determine if there were any differences in the energy consumption between habitat types (R Core Team 2015).

Results

A total of 128 invertebrate heads from 14 families were analyzed from salmonid stomach samples. Individuals from the families Hydropsychidae and Baetidae made up 35.9 and 24.2% of the total number of individuals consumed, respectively (Table 1). Salmonids in reference conditions consumed, on average, one whole invertebrate more (4.05 invertebrates) than salmonids in simulated habitat conditions (3.07 invertebrates) (Table 2). However, invertebrates with higher caloric values were consumed by salmonids in simulated habitats (Table 2).

Table 1.– Sample size of invertebrate families found in reference and simulated habitat Chinook salmon diets.

Reference Family	n	Habitat Family	n	Total % Composition
Ameletidae	2	Ameletidae	0	1.56
Anisoptera	0	Anisoptera	1	0.78
Baetidae	23	Baetidae	8	24.22
Culicidae	7	Culicidae	3	7.81
Gammaridae	9	Gammaridae	0	7.03
Heptageniidae	1	Heptageniidae	2	2.34
Hydrachnidiae	1	Hydrachnidiae	0	0.78
Hydropsychidae	24	Hydropsychidae	22	35.94
Leptoceridae	1	Leptoceridae	0	0.78
Nemouridae	2	Nemouridae	0	1.56
Perlidae	2	Perlidae	0	1.56
Phoridae	3	Phoridae	1	3.13
Simulidae	2	Simulidae	0	1.56
Unknown	8	Unknown	4	9.38
Zygoptera	0	Zygoptera	2	1.56
TOTAL	85		43	

Invertebrate diversity among treatment groups (H and R) experienced minimal variation, and differences in ellipses were minimal, illustrated by the NMDS ordination (Figure 1). Additionally, there was not enough evidence to suggest a difference between energy consumption levels of salmonids in the two habitat types (p -value = 0.43, $df = 34$, $F = 4.14$).

A total of six dominant invertebrate families were identified across all 150 drift samples (50 morning, 50 noon, and 50 evening samples). Family Baetidae was the most prevalent with an average drift concentration of 0.04 mg/m^3 followed by family Heptageniidae (0.02 mg/m^3) (Table 3). Based on NMDS ordination there was evidence to suggest that there were differences between diets and drift samples due to minimal ellipse overlap (Figure 2). Large variations in family densities among drift and diet samples provided evidence to suggest why there was minimal ellipse overlap.

Table 2.– Calculated caloric intake values from invertebrate head widths of 35 juvenile Chinook salmon separated by reference (R) and simulated habitat (H). x represents the number of fish in each habitat. n represents the total number of invertebrates found in juvenile Chinook salmon diets.

Variable	R	H
x	21	14
n	85	43
\bar{X} Invertebrates Consumed	4.05	3.07
Mean Caloric Intake (kJ)	0.09	0.13
kJ Invertebrate ⁻¹	0.02	0.04

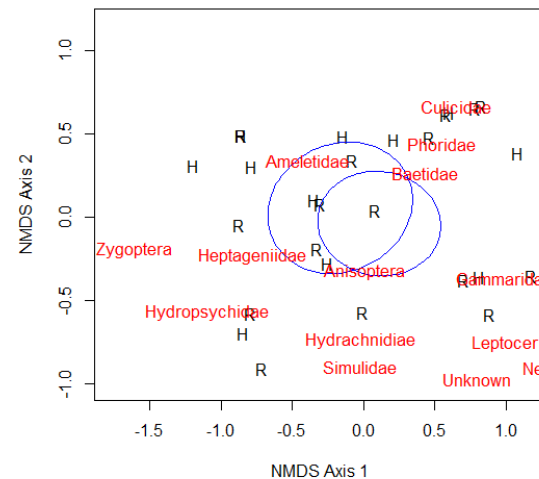


Figure 1.– NMDS (nonparametric multidimensional scaling) ordination that illustrates the variations in invertebrate diversity by habitat type (final stress for two dimensions = 0.127). A 95% confidence region is illustrated by the ellipse of each habitat type.

Discussion

The use of different prey types by juvenile Chinook salmon paralleled prey availability which

Table 3.– Average mg/m³ of invertebrate families found in 150 drift samples.

Family	Mean	95% CI	LCL	UCL
Hydropsychidae	0.008	0.028	-0.020	0.036
Baetidae	0.040	0.064	-0.025	0.104
Heptageniidae	0.022	0.093	-0.071	0.115
Chironimidae	0.007	0.012	-0.005	0.018
Simuliidae	0.001	0.003	-0.002	0.004
Amphipod	0.002	0.010	-0.009	0.012

resulted in a diet dominated by caddis and mayfly larvae in both reference and simulated habitat types. Overall, Chinook salmon were opportunistic foragers, feeding on a variety of different invertebrate families which included: Perlidae (stoneflies), sub-order Anisoptera (dragonflies), sub-order Zygoptera (damselflies), sub-order Amphipoda (scuds), and Culicidae (mosquitoes). However, at the time of this study, juvenile Chinook salmon had a tendency to select net-spinning caddis and mayfly larvae. These patterns of selecting larger bodied invertebrates likely reflect size-selective feeding by Chinook salmon, a behavior repeatedly reported for salmonids (e.g., Allen et al. 1981; Meissner and Muotka 2006). The selectivity behavior by salmonids could provide evidence to suggest why there were no differences in invertebrate communities between areas of simulated habitat and reference points. Based on our findings, Chinook salmon may not need to rely on suitable habitat, such as CWD, to consume a healthy prey amount.

The use of two different habitat types (simulated habitat and no habitat) did not yield two different diets among juvenile Chinook salmon. Our prediction was that salmonids that were situated in simulated habitat enclosures would consume a more diverse population of invertebrates, especially drift susceptible invertebrates, when compared to reference salmonids. However, our data suggest that invertebrate diversity between simulated and reference habitats were similar. Studies from Nakano and Kaeriyama (1995) and Young et al. (1997) both state that salmonids use foraging sites to minimize energy and maximize the availability of drifting species. Although our test salmonids consumed drift susceptible invertebrates, reference salmonids consumed the highest proportion. One likely reason for this phenomenon could be linked to a low frequency of interference by structures upstream of the reference enclosure which would allow drift susceptible invertebrate to drift freely. Habitat complexities are vital for a lotic ecosystem which has the ability to produce an array of invertebrate populations (Merz and Chan 2005), but testing

whether invertebrate populations varied between simulated and reference habitats proved to be difficult. In order to determine invertebrate diversities among sites, future studies should incorporate a larger study area with a wide array of substrate types. When studies are confined to a localized area, invertebrate diversity among sampling sites can be very low.

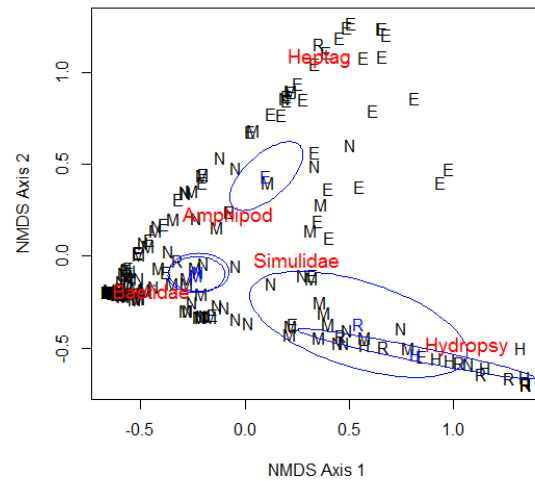


Figure 2.– NMDS ordination for drift samples from morning (M), noon (N), and evening (E) along with stomach contents from each habitat type (H and R). Minimal stress (0.041) was present at only two dimensions (McCune and Grace 2002). The ellipse denotes a 95% confidence region and the families (in red) listed are those that are most likely associated nearby samples.

Studies have shown that juvenile Chinook salmon's diet closely resembles benthic and/or drift invertebrates (Allan 1981; Bres 1986; Esteban and Marchetti 2004). Our data provides evidence to suggest that juvenile Chinook salmon have a tendency to favor benthic invertebrates compared to drift species. Difference between diets and drift samples could be linked to a large number of Hydropsychidae invertebrates consumed by the salmonids. Due to an enclosure-type study, the ability to forage for prey was limited to a given boundary; the benthic species of the family Hydropsychidae could be the easiest species to forage on with the limitations of an enclosure. Also, variability in the sediment regime among the study reach may have contributed to a difference between salmonid diets and drift samples. Areas of uniform substrate, such as sand, can contribute to low invertebrate diversity (Merz and Chan 2005; Negishi et al. 2002). When comparing drift to benthic species, larger individuals (e.g., cased Trichoptera,

Plecoptera, Megaloptera) are known for being poorly represented in drift samples, but are commonly found in diets of salmonids (Rundio and Lindley 2008). Species from the order Ephemeroptera, susceptible to drift, have been confirmed visually being consumed by salmonids (Rundio and Lindley 2008); however due to the relatively small size of an individual Ephemeropteran, the digestive rate of a juvenile Chinook salmon could bias an individual family within the dietary analysis (Bromley 1994; Paakkonen et al. 1999; Sveier et al. 1999). The majority of our salmonids were collected during the morning hours, thus stomach samples presumably reflected the period of elevated feeding associated with evening hours (Utz et al. 2012).

The most surprising discovery of our study was that salmonids had a tendency to select benthic invertebrates over drift intolerant individuals; as well as not being able to determine any significant difference in diets between habitat types. As mentioned earlier, we hypothesized Chinook salmon to have a more abundant and diverse invertebrate diet in simulated habitat conditions than reference conditions which our data suggests otherwise. Studies on salmonids and invertebrate assemblages on the Merced River have found that species belonging to the families of Baetidae and Hydropsychidae are the most common taxa observed within diet and drift samples (Utz et al. 2012; Albertson et al. 2011). In order to make accurate assumptions on feeding habits future studies might consider attempting to make behavioral observations of individual fish at all times of day and in different seasons in order to represent different prey availabilities.

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